No. 6.] [SEPTEMBER, 1877.

THE MINERALOGICAL MAGAZINE AND JOURNAL OF THE Mineralogical Society OF GREAT BRITAIN & IRELAND

INSTITUTED 3rd FEBRUARY, 1876.

EDITED BY THE HON. SECRETARY.

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THE MINERALOGICAL SOCIETY

Mineralogical Society of Great Britain & Ireland.

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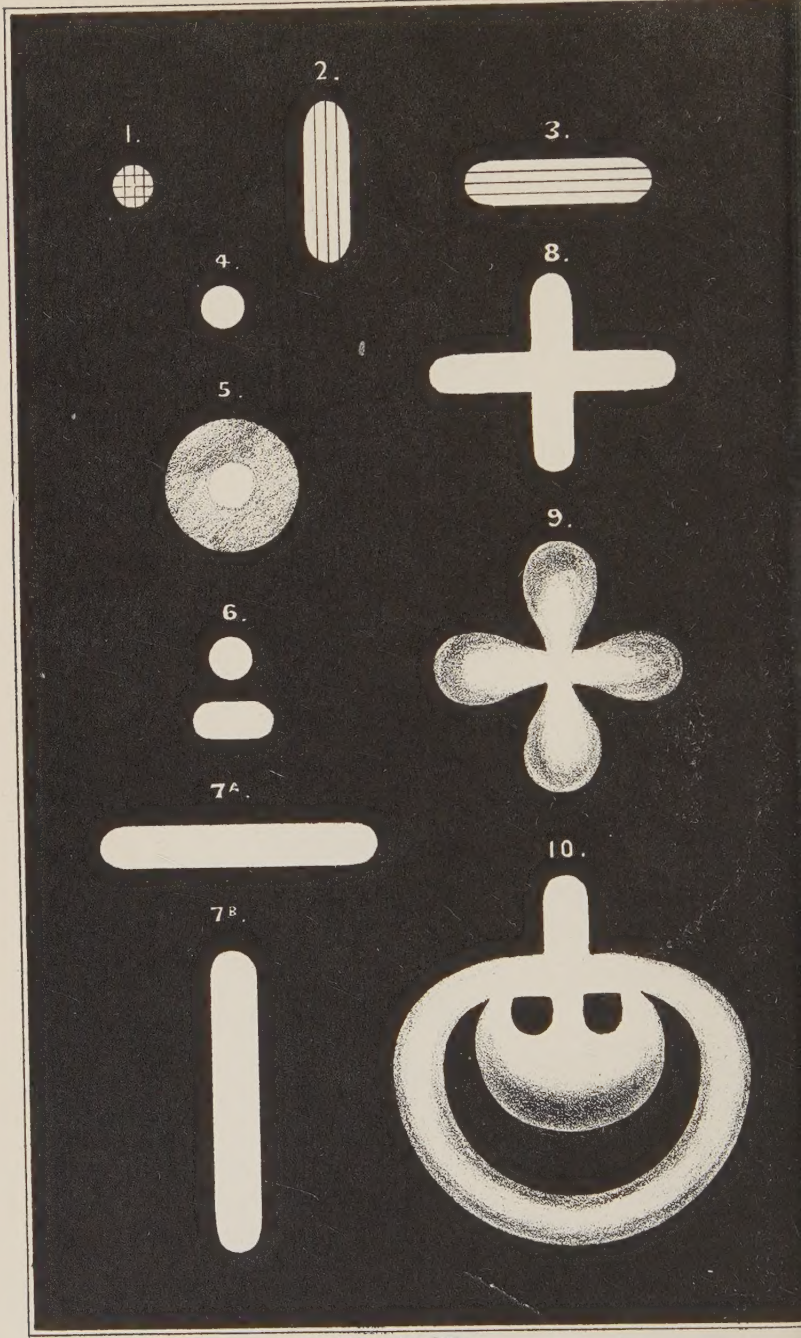

LAKE & LAKE, TRURO.

EXCERPT MINUTES OF COUNCIL MEETING,

Held at the Athenæum, Plymouth, on Wednesday, August 15th, 1877.

H. C. Sorby, Esq., F.R.S., *President,* in the Chair.

Resolved—That the following gentlemen having been duly proposed in accordance with the rules, be elected, viz. :—

CORRESPONDING MEMBERS.

Prof. K. J. V. Steenstrupp, of Copenhagen.
Prof. Johnstrupp, Copenhagen.
Prof. Waage of Christiania.
Prof. Kjerulf of Christiania.
Pastor Esmark of Christiania.
Prof. Nordenskjold of Stockholm.

MEMBERS.

Dr. Chas. O. Trechmann, of 106, High Street, Hartlepool.
Mr. G. S. Boulger, F.G.S., of 8, Westbury Road, Harrow Road, London.
Mr. Thos. W. Miller, C.E., of the Royal Mint, London.

ASSOCIATES.

Mr. Wm. Semmens, of Liverpool.
Mr. W. M. Hutchings, of the Laboratory, Great Float, Birkenhead.
Mr. Walter Richardson, of Leeds.
Mr. J. P. Cornforth, of Tuebrook, near Liverpool.
Mr. Richard Maynard, of Pendarves Street, Tuckingmill Cornwall.
Mr. Thos. Clark, of Fairmantle Street, Truro.

Resolved—That the election of Mr. T. A. Readwin, F.G.S., as Local Secretary for the Liverpool district, be and hereby is confirmed.

SECOND ANNUAL GENERAL MEETING,

Held at the Athenæum, Plymouth, on Wednesday, August 15th.

H. C. Sorby, Esq., F.R.S., *President,* in the chair.

The President called upon the Secretary to read the following "Report of the Council."

COUNCIL REPORT.

This is the second Annual Meeting of the Mineralogical Society of Great Britain and Ireland, and although it has only been established 18 months, we may congratulate ourselves on the work already accomplished.

The printed "List" contains the names of 4 corresponding members, 13 life members, 112 annual members, and 12 associates; and your Council has this day elected 9 additional members, and 6 associates, making the present numbers of the Society amount to 156.

The Journal, five numbers of which have been already issued, would do credit to any Scientific Society in existence—either as regards its contents, or its appearance.

It has become known to Mineralogists in all parts of the world, and we now exchange publications with Societies and individuals in the United States, Canada, Australia, Germany, and Italy. This commencement of a Library of Reference appears to point to the desirability of framing some rules to regulate the circulation of books among the members, and the Council proposes to take this into consideration at an early date.

The Council takes this opportunity of suggesting that it might serve to advance the interests of our science, if members would contribute microscopical preparations of rocks and minerals. It also invites contributions of typical specimens of new or rare mineral species described in the journal, although there might be difficulty in providing accommodation for any general collection of minerals.

Members and Associates are recommended to avail themselves of the pages of the Mineralogical Magazine, as a means of effecting exchanges of duplicate specimens, or of obtaining information on subjects connected with our science.

The Balance Sheet, which has already been placed in the hands of the members, shews that in addition to the sum of £105, the amount of composition fees funded in accordance with Rule 8, there remained at the end of the year 1876, a balance of £28 18s. 3d. in favour of the Society.

Since the last Annual Meeting, held at Glasgow, a General Meeting has been held in London, and Local Meetings at Camborne and at Liverpool. At all these meetings important papers have been read.

The voting papers now placed upon the table have been examined by the Auditors, and they announce that the following gentlemen are elected as office-bearers for the ensuing year. :—

PRESIDENT.

Mr. H. C. Sorby, F.R.S.

VICE-PRESIDENTS.

The Rev. Professor Haughton, M.A., F.R.S.
Prof. M. Forster Heddle, M.D., &c.

COUNCIL.

Mr. Thos. Davies, F.G.S., &c.
Mr. T. M. Hall, F.G.S., &c.
Mr. M. H. Johnson, F.G.S., &c.
Dr. Robert Oxland, F.C.S., &c.

(In place of Messrs. Bonney, Crookes, Nicol, and Rudler, who retire by rotation).

TREASURER.

Mr. R. P. Greg, F.G.S., &c.

GENERAL SECRETARY.

Mr. J. H. Collins, F.G.S., &c.

FOREIGN SECRETARY.

Dr. C. Le Neve Foster, F.G.S., &c.

AUDITORS.

Mr. B. Kitto, F.G.S., &c.
Mr. F. W. Rudler, F.G.S., &c.

Your council has now only to congratulate you on what has been done in the past, and to urge that every member should exert himself to increase the strength and the income of the Society by proposing suitable persons for election as members and associates.

The Report was unanimously adopted.

The President then delivered his address "on the determination of the chief optical constants of minerals by means of a new class of optical properties," after which the following papers were read and discussed :—

1.—On the distribution of minerals in North Devon, by T. M. Hall, F.G.S.

2.—On the microscopical characters of Luxullianite, by the Rev. T. G. Bonney, M.A.

3.—Note on Duporthite, a new asbestiform mineral from St. Austell Bay, in Cornwall, by J. H. Collins, F.G.S.

4.—On a new form of Phosphorite from Southern Russia, by H. H. Gunn, Assoc. R.S.M.

5.—Notes on some Norwegian minerals, by T. A. Readwin, F.G.S.

6.—Further notes on mineral growth, by T. A. Readwin, F.G.S.

Specimens in illustration of their papers were exhibited by Messrs. Collins and Gunn.

Professor Harkness exhibited a new variety of crystallized quartz, having pearly lustre, which had been found by Miss Cotter, near Cork, and which he proposed to call Cotterite, after the discoverer.

After the papers had been read and discussed, the President illustrated his new methods of examining minerals by means of the microscope, and many prepared sections of calcite, aragonite, fluor, orpiment, and other minerals.

The Meeting concluded with a hearty vote of thanks to the chairman for his valuable and original address, and for his conduct in the chair.

BOOKS RECEIVED.

From *Reale Comitato Geologico d'Italia.* Bolletino, No. 5 e 6, 1877.

„ *Prof. P. Groth, Strasburg.* Zeitschrift für Krystallographie und Mineralogie. Heft. 5.

„ *Prof. Archibald Liversidge, Sydney.* On the formation of "Moss-gold" and "Moss-silver."

„ „ On a remarkable example of contorted slate.

„ „ On a fossiliferous deposit from the Richmond River, N. S. W.

„ „ The Minerals of New South Wales.

„ *Prof. Jas. D. Dana, Newhavern.* American Journal of Sience, Aug., 1877.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL

OF THE

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND.

No. 6. SEPTEMBER, 1877. Vol. 1.

ADDRESS, &c.,

By H. C. Sorby, F.R.S., &c., *President.*

INTRODUCTION.

IN commencing the proceedings of the second Annual Meeting of the Mineralogical Society of Great Britain and Ireland, allow me to express the pleasure which it gives me to be present here to-day, and my regret that I was not able to attend the first meeting last year at Glasgow. I feel it to be incumbent on me to give some opening address, but at the same time it must not be long, since many other subjects claim attention.

In the first place I think I may well congratulate the Society on its present condition, and contrast it with some of the predictions made little more than a year ago. We were told by men well-known in the mineralogical world that no such Society as our own could possibly be established—that, even if it could, it would be of no use, unless it published a Journal—which it most certainly never could afford. However, these very confident predictions have proved untrue. Our Society has been fairly established, and it has been able to publish what I think we may look upon as a very satisfactory journal. The time at my disposal is too short to make it desirable to pass in review the various memoirs that have been published, but I may refer to the ten papers read at our last meeting

in London, as a proof of the increased interest taken in our science, awakened, I am persuaded, in great measure by the establishment of a society specially devoted to the advancement of mineralogy.

At that meeting I promised to give on the present occasion a full and complete account of a new method for determining the index of refraction of minerals, which could readily be employed as a means for their identification. A short preliminary notice of this method was published in vol. I, p. 97 of our Journal. The whole subject was then in its infancy, and I little thought that it would lead to an entirely new branch of mineralogical study, and to the discovery of a new class of optical properties of crystals. Since that meeting my time has been almost exclusively occupied with this inquiry, and the subject has grown so large that if, as I promised, I were to give a complete account of the construction and use of the instrument, I should occupy the whole time that can be devoted to this meeting. I must, therefore, merely give such a general account of the subject as will suffice to prove that we have at command an entirely new and very ready means for observing many of the leading optical characters of crystals; and provided that a mineral is sufficiently transparent over an area $\frac{1}{20}$th of an inch in diameter, and is not too thin, we may obtain data of the very greatest value for its identification.

Before describing the various remarkable phenomena which may be observed, it will be well to give a short history of my subject.

At the meeting of the Royal Microscopical Society last November, Dr. Royston-Pigott exhibited and described an instrument which he named a *refractometer*. His paper was subsequently published with a plate in the Monthly Microscopical Journal.* The principle made use of in applying this instrument was the increase in the focal length of the object glass of a microscope, caused by looking through media of different refracting power. The author showed that if t be the thickness of this medium, and d the amount of the displacement of the focus, the index of refraction μ may easily be calculated from the following equation.

$$\mu = \frac{t}{t-d}$$

In the instrument described by Dr. Royston-Pigott, the amount of this displacement, and also the thickness of the object under

* Vol. XVI, 1876, p. 294.

examination, were determined by means of a micrometer screw fixed under the stage of the instrument, in such a manner that it became unsuitable for use as an ordinary microscope.

At the time of the reading of this paper I was much struck with the general method employed, and in the subsequent discussion I said that probably some modification of it might prove very useful in studying minerals. I have now succeeded in proving this very completely.

From the first I was anxious to contrive some arrangement that would enable us to obtain the necessary data with an ordinary microscope, or at all events with one so slightly modified as not in any way to interfere with its general use; and I think that I have succeeded in accomplishing this by a very simple addition, which will also enable us to use the instrument for a number of purposes not originally contemplated.

Practically the application of the method I propose is very simple. If an object be placed on the stage of a microscope and the focus adjusted, on placing over it a plate of some highly refracting substance the focal length is increased, and hence to bring the original object into focus, the body of the microscope must be moved farther from it. In order to measure the amount of this displacement, nothing, therefore, is required but some means for accurately measuring the distance over which the body of the microscope is thus moved. This may be roughly done with a small scale, accurately divided to $\frac{1}{100}$ths of an inch; but it is far better to have an attached scale and vernier, so as to be able to read to $\frac{1}{1000}$th of an inch, and to estimate half that quantity. The thickness of the specimen is easily measured by focusing first the particles of dust on the surface of the glass plate supporting the mineral, and then those on its upper surface. Several observations should be made of the position of these different planes, as shown by the readings on the scale, and the means taken, in order to compensate for small accidental errors, and care must of course be taken to avoid any that might be caused by imperfections in the instrument. If the section of the mineral be covered with thin glass, which in most cases is very desirable, its apparent thickness must be measured, and due allowance made for it in calculating out the results. In order to obtain as accurate measurement as possible, a number of precautions must be taken, which are all simple enough, but it

would occupy too much time to describe them in detail. With proper care the errors in the values of t and d ought to be certainly less than $\frac{1}{1000}$th of an inch. The accuracy with which the indices of refraction can thus be determined depends much on the thickness of each specimen, but if it be from $\frac{1}{8}$th to $\frac{1}{4}$th of an inch, the errors ought to be limited to the third place of decimals. In practically employing this method it is of great importance to have some object which gives a very definite focus. In the first instance I made use of a glass plate having very fine parallel scratches, made with the finest emery paper; but I soon found that it would be very convenient to have more definite and equidistant parallel lines, not in any way affected by moving the stage. This can be accomplished by having them ruled $\frac{1}{100}$th of an inch apart on a glass plate, fixed as far as possible below the lenses of an achromatic condenser, with a small central stop, which gives at the focus a much reduced image easily adjusted either a little below the lower or upper surface, or nearer the centre of the specimen, according as its shape may make it necessary, so that the light may pass to the object glass as equally as possible from all sides. It is also extremely useful to have an iris diaphragm fixed just below the grating, so as to be able also to obtain an image of a circular hole of any requisite diameter. The object glass usually employed was a $\frac{2}{3}$, stopped down to an aperture of 13°; this, with a No. 2 eye-piece, gives excellent results. I had two sets of lines ruled on the same surface at right angles to each other, in order that there might be less chance of mistaking any striæ in the mineral for a single system of lines, and that either system might be used if the other were obscured. This arrangement has fortunately led to the discovery of an entirely new class of optical properties. These have been described in detail in a paper read at the Royal Society, on June 21st, which was followed by another by Professor Stokes, in which he has treated the subject mathematically, and proved that these remarkable properties can be fully explained by the known laws of double refraction, and might have been predicted, though no one appears to have either described the facts or considered the question theoretically. I now purpose to give a general sketch of the subject as thus developed conjointly by myself and Professor Stokes.

Unifocal and Bifocal Images.

On looking at the double system of lines on the grating, limited to a small circular opening by the diaphragm, without any intervening object, both sets of parallel lines are seen at the same focus as shown by fig. 1. If a plate, with parallel flat surfaces of glass or of any transparent mineral which has no double refraction, be placed on the stage of the microscope, with its surfaces perpendicular to the line of vision, the two systems of lines can still be seen at the same focus, no matter what may be the azimuth of the lines to the axes of the crystal. The image may thus be said to be *unifocal*, and to have no special *focal axis*. The index of refraction, determined as above explained, is that of an ordinary ray. On the contrary, if the mineral possesses double refraction, the phenomena seen by means of the extraordinary ray may be totally different, and as though a cylindrical lens had been placed in front of the object glass. In order to be able to examine separately the two rays polarized in opposite planes, a Nicols' prism must be used over the eye-piece, arranged at such an azimuth as to transmit one or other ray alone. The ordinary ray has just the same properties, and is strictly unifocal, no matter what may be the direction of the section of the crystal; but the characters of the extraordinary ray differ greatly, according as the section is cut perpendicular, oblique, or parallel to the principal axis. As an example, I cannot possibly refer to any mineral more suitable than calcite. On examining the grating through a section parallel to the axis, about $\frac{1}{5}$th of an inch thick, the plane of polarization of the Nicol being arranged perpendicular to the axis of the crystal, so that only the extraordinary ray is transmitted, it will be found that at two different foci the circular hole is elongated in opposite planes, and that both sets of lines are invisible, unless they are nearly parallel and perpendicular to the axis, and that there are two focal points, separated from one another by an interval somewhat more than $\frac{1}{8}$th of the thickness of the section, at each of which only one system can be seen at once, as shown by figs. 2 and 3. The image is thus truly *bifocal*, and has a definite focal axis, and the lines are distinctly visible only when parallel or perpendicular to this axis. On being rotated they disappear, and the other system appears at a different level. When determined in the manner already explained, the index of refraction for the lines parallel to the principal axis of the crystal is the true

index of the extraordinary ray, whereas that for the lines perpendicular to this axis is only an *apparent* index, and is equal to the square of the index of the ordinary ray, divided by that of the extraordinary. The principal axis of the crystal is thus the focal axis of the image. Though much less perfectly, these facts may be observed by using instead of the grating a glass plate with rectangular fine scratches, made with the finest emery paper, placed directly under the object.

The striking difference between a unifocal and a bifocal image becomes at once intelligible, if instead of a grating, we examine through the mineral the image of a small circular hole, as fig. 4. In the unifocal image this is seen undistorted, well defined all round at one definite focus; whereas in the bifocal image there is no focal point whatever at which the hole can be seen of its true size and shape. There is one focal point for the two opposite sides of its circumference which are parallel to the focal axis, and at this focus the circle is drawn out parallel to that axis into a long band, and there is another focal point for those parts of the circumference which are perpendicular to the axis, and the image is then drawn out in a direction perpendicular to that of the former image, as shown by figs. 7*a* and 7*b*. At intermediate focal adjustments we see merely a large circle without any defination. It therefore follows that the series of black points forming a line would be similarly drawn out at the two foci into lines, and if these overlapped, as they would, if the line were at that particular azimuth, we should appear to have a well-defined black line, whereas at other azimuths this line would be spread out into a band, and so diluted with white light, as to be practically invisible. In a section parallel to the axis the images of the small hole are directly superimposed, but if we examine it through a section parallel to the cleavage they are widely separated in the plane of the principal axis, as shown by fig. 6, and appear to lie at different levels. That due to the ordinary ray remains in the centre of the field, and is not in any way distorted, whereas that due to the extraordinary ray is thrown out of the centre from the line of axis, and is both distorted and fringed with colour. This image is very decidedly bifocal, but one system of lines is much obscured by coloured fringes, unless we illuminate with the approximately monochromatic light transmitted by red glass. When the section is cut in planes more and more inclined to the axis, the bifocal image becomes more and more nearly unifocal, and when the section is perpendicular to the axis it is

unifocal, but can be distinguished from that due to the ordinary ray by causing the light to pass obliquely. A specimen, $\frac{1}{4}$th of an inch thick, shows the two images with both sets of lines, at perfect focus, directly superimposed at two very widely separated levels, as though there were two sets of lines ruled on opposite sides of a glass plate. One gives the true index of refraction of the ordinary ray, and the other an apparent index, which is equal to the square of the true index of the extraordinary ray, divided by the true index of the ordinary. On examining the small circular hole it is seen undistorted, in perfect focus, at two widely separated foci, surrounded with a large nebulous circle, due to the other image seen out of focus, as shown by fig. 5.

All these phenomena are totally unlike what can be seen with the naked eye in looking directly through sections cut either parallel or perpendicular to the axis. A white or black spot placed close to the specimen is then not even divided into two. The phenomena seen with the microscope depend entirely on the power of the object glass to collect divergent rays. In the case of substances having no double refraction, this divergence merely obeys the laws of ordinary refraction, and enables us to measure the index in the manner already explained; but, in the case of the extraordinary ray, the light is bent from the normal line unequally and in opposite directions, and may thus enter the object glass at an angle of divergence greater or less than that depending on the index of refraction, according to the direction of the section, and to whether the double refraction is negative or positive. Thus, for example, in the case of calcite cut perpendicular to the axis, the light diverges abnormally and equally all around the axis, and therefore the focal point of objects seen through the section is made abnormally short, and the apparent index abnormally small, being in fact only 1·332, whereas the true index of the extraordinary ray is 1·480, and of the ordinary 1·658.

Crystals like orpiment or aragonite, which have two axes of double refraction, and three different indices, have no ordinary ray, and no permanently unifocal image, but two bifocal images polarized in opposite planes. We may thus have four different apparent indices, but in sections cut in particular directions one or two pairs may become equal, so as to give rise to unifocal images, which, however, differ from the unifocal image due to an ordinary ray in becoming bifocal when one half of the front of the object-glass is covered by a stop.

As an example of a crystal giving two bifocal images, I may refer to orpiment. A small circular hole, seen through a section parallel to the cleavage, is drawn out at different foci, into two crosses as shown by fig. 8, each cross being produced by the combination of two bands of light polarized in opposite planes, each due to an extraordinary ray, analogous to the single extraordinary ray of calcite. In the case of aragonite, cut perpendicular to the principal axis, the arms of the crosses are more equal, but spread out in the manner shown by fig. 9. This is apparently due to the crystal being made of portions having their axis nearly but not absolutely parallel. If the section is in a plane somewhat oblique to the principal axis, one bar of the cross is distorted into an irregular circle, and one arm of the other bar is spread out into a sort of crescent, so that we see the curious appearance shown by fig. 10.

A remarkable peculiarity of crystals which thus give two well pronounced bifocal images, is that though they may be perfectly transparent, and distant objects distinctly visible through them with the naked eye, the systems of lines at right angles to each other are perfectly invisible with the microscope, except at particular azimuths. I was extremely surprised at this fact when first I observed it, and could not understand the reason of this apparently strange peculiarity.

When the section is cut parallel to the principal and to one of the secondary axes, we obtain a cross with unequal arms at four different foci; and when cut parallel to the principal, and along the diagonal of the secondary axes, one image has the bifocal characteee very strongly developed, and the other is almost or quite unifocal, but can be shown to be also due to an extraordinary ray, by causing the light to pass obliquely.

It will thus be seen that by examining the small hole and the grating through the various crystals, we may learn not only what are their general optical properties, but also by the superposition or displacement of the images, what is the direction of the section under examination.

If we wish to ascertain the real value of the indices, we must bear in mind the following facts. The light passing through substances not possessing double refraction, and the ordinary ray of crystals belonging to the rhombohedral and dimetric systems, have no special focal axes, and the apparant index for the truly unifocal

image is the true index, no matter what may be the direction of the section. Doubly refracting crystals give two images, one or both bifocal and have one or three principal focal axes, according as they have one or two optic axes. These focal axes are invariably perpendicular to the plane of polarization of the images, and their direction may thus be determined with accuracy, if the section can be examined side ways with polarized light. In the case of any bifocal image, one of the apparent indices is true only when the corresponding principal focal axis is parallel to the plane of the section. If, therefore, a natural or artificial plate of a two axed crystal be parallel to two principal axes, each image gives one true index, and the third can be calculated. If, however, parallel to only one axis, only one index can be determined, whilst if not parallel to any axis, none of the true indices can be directly measured.

When the section is parallel to two of the focal axes, the three true indices being μ, μ', μ'', the four apparent indices are

Polarized in one plane.		Polarized in the opposite plane.	
μ	(a)	$\frac{\mu''^2}{\mu'}$	(c)
$\frac{\mu''^2}{\mu}$	(b)	μ'	(d)

Hence $\mu''=\sqrt{a\ b}$ or $\sqrt{c\ d}$ It also follows that $\frac{a}{d}=\frac{c}{b}$; but, since none of the observed values may be accurate, this relation may not be found to be strictly true. By dividing any discrepancy equally between the four apparent indices, we may deduce the most probable values of the three different true indices, providing, of course, that the discrepancies are due to errors of observation and not to the section being inaccurately cut.

Some apparently anomalous results are seen in minerals which have such a strong dichroism that one image is completely absorbed. Thus, for example, green tourmaline and clinochlore appear to have only one bifocal image, although both of them have strong double refraction. Various other special peculiarities might be named if time would permit. My aim is to give a general outline of the whole subject, which is fully discussed in papers by myself and Professor Stokes, to be published in the proceedings of the Royal Society. On the whole we have been able to

draw the following conclusions:—crystals having no double refraction give only one image, which is strictly unifocal; crystals having only one optic axis give two images, one truely unifocal and the other bifocal, unless the section is nearly perpendicular to the optic axis; and crystals having two optic axes give two images. both of which are bifocal, unless the section is nearly parallel to four different planes much inclined to the plane of the optic axes, The separation of the focal points in bifocal images varies directly as the intensity of the double refraction and the thickness of the specimen; and, if the double refraction be weak and the section too thin, the bifocal character of the image may not be recognizable. Sometimes, however, as in orpiment, the difference in the focal distances amounts to more than $\frac{1}{5}$th the thickness. As a general rule, all the more important facts may be observed qualitatively, if the specimens of the different minerals be from $\frac{1}{8}$th to $\frac{1}{4}$th inch thick, no matter what may be the direction of the section, though it may not be suitable for determining the true value of the indices. The natural planes of crystals belonging to all those systems in which the axes are rectangular are, however, often in the proper direction; and, unless their surfaces be very irregular, perfectly satisfactory results may be obtained by mounting the specimens on glass and fixing over them a thin glass cover with Canada balsam, or by using oil of Cassia or some other liquid of nearly the same refractive power as the specimen under examination, if it be desirable not to use balsam.

Applying this method to the study of various minerals, the difference between them is found to be very great. We can, usually, at once see whether they give a single unifocal image or one or two bifocal images, and form a very good opinion respecting the intensity of the double refraction, and easily determine whether it is positive or negative.. There can never be any question as to the index of the ordinary ray since the observed index is always true, and in many cases the index or indices of the extraordinary ray can also be determined. All these facts combined furnish data so characteristic of the individual minerals, that it would usually be difficult to find two approximately similar. In any case we have data which may often be of the greatest assistance in identifying the different species. Of course this method cannot be employed if the specimens are opaque, or have such a fibrous or laminar structure as to prevent our distinctly seeing the lines of

the grating. The presence of a vast number of fluid-cavities and minute crystals or granular may not, however, signify very much, and if a sufficiently solid and clear space $\frac{1}{20}$th of an inch in diameter can be found, all the necessary facts may be observed. To be able thus comparatively easily to determine the principal optical constants from such a specimen, without its having been previously cut in any special direction, is surely as much as we ought to desire, and more than one might have thought possible.

Connexion between the indices and chemical composition.

My attention has lately been much directed to another question connected with my subject. Assuming that the index of refraction of a mineral is known, is it possible to deduce from it any definite conclusions? In order to answer this question I have drawn up a table of the indices of about 80 different minerals, including those given by Des Cloiseaux in the very valuable catalogue published in the *Annuaire du Bureau des Longitudes* for 1877, and my own measurements. It was necessary to compare the mean indices, and when there are three, I have taken the average. When there were only two, I have doubled the index of the ordinary ray, added that of the extraordinary, and divided by three. We may discuss the results in two different methods. We may compare the indices in their natural condition, or may eliminate the effects of difference in density, and compare the *absolute* refractive power of different substances.

It has been shown by Biot and Arago that for gases, more or less compressed, μ being the index of refraction and δ the density, $\frac{\mu^2-1}{\delta}$ is a constant quantity. By applying this method of comparison to minerals which have a different density and refracting power, but the same composition, like calcite and aragonite, opal and quartz, this absolute refractive power is found to be the same. In carrying out this inquiry we, however, soon find that the data are very imperfect. The specific gravity of the specimens used to observe the indices is not given, and the only course open is to adopt the most probable values which have been determined independently. Still, notwithstanding the various sources of uncertainty, we may, I think, draw a number of provisional conclusions, which, though their use may be limited, may at all events point out the feasibility of a new line of enquiry.

Proceeding in this manner, I have constructed the two tables given at the end of this address, one of which shows in ascending order the indices of refraction, and the other the absolute refracting powers. Each has its special advantage, and the two combined clearly show what a very great deal may be learned from a knowledge of both the refracting power and the density.

On examining the table of simple indices, we at once see that the value of the index depends so much on the special density of each particular mineral that the influence of the chemical composition is much obscured; we may, however, draw several important conclusions. In the case of minerals not silicates, we see that ice and water have the lowest indices. Then come the fluorides which have a lower index than any other class of minerals. Nearly all the hydrous earthy minerals and those soluble in water have indices less than that of quartz. All the earthy carbonates, sulphates, and borates have indices between those of quartz and corundum. All those minerals which have an index greater than that of corundum are metallic or metalloidal, titanates, molybdates, or tungstates. Sulphur and the sulphides have all indices above 2·000, and the arsenides above 2·500.

In the case of the silicates and aluminates we see that all the zeolites have indices less than that of any anhydrous silicate. All those containing much water, potash, or soda, have indices under 1·600. No rule can be given for those having indices between 1·600 and 1·700; those having indices between 1·700 and 1·800 contained much alumina, lime, or iron. None but zircon and those varieties of garnet which contain much iron have a greater index than that of corundum. Zircon alone has an index considerably above 1·800.

Though our general conclusions are thus limited, yet when we come to compare the indices of the individual minerals, we can see clearly enough that they alone would suffice to distinguish many minerals from one another, provided that we could rely on there being no greater error than a single unit in the second place of decimals. Thus, for example, it has been said that in studying the microscopical structure of rocks it is often difficult to distinguish nepheline from apatite. The index of nepheline is about 1·53, whereas that of apatite is 1·64, and such a considerable difference could easily be recognised in a section not less than $\frac{1}{50}$th of an inch thickness.

When we know both the index of refraction and the density of a mineral and can thus calculate out the absolute refracting power, the effect of chemical composition becomes more apparent, as is well shown by the tables. In the case of minerals, not silicates or aluminates, we find that the fluorides have a very low absolute power. None of the phosphates, tungstates, or anhydrous earthy or metallic sulphates, or carbonates, have a greater power than that of calcite. The refracting power of all the chlorides, borates, molybdates, titanates, and of the hydrous sulphates and carbonates, is intermediate between those of calcite and water. Mellite, sal-ammoniac, chromate of lead, and all the highly metallic and metalloidal minerals have a power greater than that of water. Sulphur and the sulphides of arsenic alone have one above 1·500. In the case of silicates and aluminates we see that topaz from containing fluorine has a very low power. Those having a power greater than ·500, and less than that of quartz contain much potash, soda, or magnesia. Those having a greater power than that of quartz or corundum, but materially greater than ·600, are of very varying composition, but have a greater power according as they contain a greater relative amount of lime, iron oxides, and water. Zircon alone has a considerably higher power than ·600, but all the silicates and aluminates have a lower power than that of water.

On comparing the individual minerals of the different groups so as to ascertain the effects of the various bases or acids, it appears to me that there must be some definite order in their absolute refracting power. I, however, do not think that the data are sufficiently trustworthy to make it desirable to publish my results. The complex and varying composition of many minerals makes it very difficult to apply these principles in a satisfactory manner. A mixture of two substances, one having a very high and the other a very low power, would produce the same general effect as a single substance of medium power. Though this is a great difficulty, yet it does not make it altogether impossible to draw some conclusion. Thus, for example, if the absolute power of some anhydrous silicate were under ·540, we might very safely conclude that it did not contain much lime, whereas if it were above ·560 and under ·580, we might conclude that it contained a very considerable amount of lime, glucina, or iron oxides.

In conclusion, I must say that I have brought forward this question of the connexion between refracting power and chemical

composition because it has manifestly a very important practical bearing, independent of its being, perhaps, the first attempt to determine indirectly chemical composition by means of the microscope. Assuming that we may rely on the various observations, this appears to be possible within certain limits, but what the limits are cannot now be determined for want of better data. Everything depends on the combination of various different accurate observations, and unlike the first portion of my subject, the result cannot be demonstrated mathematically.

NOTE.—The illustrations given in plate VII. are drawn on different scales, and represent the appearances of a small or larger circular hole more or less strongly magnified, as is necessary to show the phenomena to advantage.

I.—Table of indices in ascending order

Minerals not Silicates.

Ice	1·305	Parisite	1·720
Water	1·333	Diaspore	1·722
Cryolite	1·350	Corundum	1·770
Fluor	1·433	Malachite	1·880
Opal, &c.	1·446	Anglesite	1·882
Borax	1·460	Sphene	1·903
Thenardite	1·470	Scheelite	1·925
Sylvine	1·480	Cerusite	1·977
Glaserite	1·490	Senarmontite	2·070
Struvite	1·502	Sulphur	2 080
Selenite	1·522	Phosgenite	2·120
Mellite	1·527	Calomel	2·170
Common Salt	1·540	Blende	2·340
Quartz	1·545	Wulfenite	2·370
Dolomite	1·572	Diamond	2·420
Uranite	1·572?	Anatase	2·533
Anhydrite	1·585	Realgar	2·540
Calcite	1·597	Greenockite	2·690
Celestine	1·623	Chromate of Lead	2·730
Aragonite	1·629	Orpiment	2·800
Barytes	1·638	Red Copper	2·850
Sal Ammoniac	1·640	Proustite	2·890
Apatite	1·641	Cinnabar	2·970
Boracite	1·668		

Silicates, Aluminates, &c.

Natrolite	1·482	Hornblende	1·627
Analcime	1·487	Tourmaline	1·634
Thomsonite	1·503	Andalusite	1·638
Epistilbite	1·510	Euclase	1·655
Harmatome	1·516	Phenacite	1·656
Adularia	1·521	Sillimanite	1·660
Leucite	1·521	Peridot	1·675
Apophyllite	1·532	Axinite	1·677
Nepheline	1·534	Augite	1·680
Iolite	1·540	Dioptase	1·680
Quartz	1·545	Spinel	1·713
Dipyre	1·553	Idocrase	1·716
Scapolite	1·559	Kyanite	1 720
Beryl	1·570	Lime garnet	1·740
Antigorite	1·574	Chrysoberyl	1·747
Chlorite	1·575	Epidote	1·750
Meionite	1·580	Staurotide	1·753
Muscovite	1·588	Corundum	1·770
Clinochlore	1·590	Iron Garnet	1·791
Melinophane	1·605	Zircon	1·970
Topaz	1·613		
Calamine	1·620		

II.—Table of absolute refracting powers in ascending order.

Minerals, not Silicates.

Cryolite	·270	Common Salt	·623
Fluor	·332	Senarmontite	·624
Barytes	·375	Malachite	·658
Anglesite	·404	Borax	·659
Celestine	·411	Wulfenite	·682
Thenardite	·425	Glaserite	·705
Cerusite	·441	Sphene	·751
Scheelite	·447	Struvite	·752
Parisite	·450	Water	·763
Uranite	·471 ?	Ice	·764
Dolomite	·511	Mellite	·821
Anhydrite	·517	Cinnabar	·910
Apatite	·522	Chromate of Lead	1·075
Opal, &c.	·522	Blende	1·100
Quartz	·525	Sal ammoniac	1·103
Corundum	·525	Red Copper	1·187
Aragonite	·563	Greenockite	1·260
Calcite	·567	Proustite	1·337
Selenite	·567	Diamond	1·374
Calomel	·572	Anatase	1·392
Phosgenite	·572	Realgar	1·527
Diaspore	·580	Sulphur	1·607
Boracite	·602	Orpiment	1·960
Sylvine	·610		

Silicates, Aluminates, &c.

Topaz	·453	Tourmaline	·542
Calamine	·472	Spinel	·543
Adularia	·519	Chlorite	·547
Muscovite	·526	Analcime	·548
Leucite	·522	Iron Garnet	·552
Iolite	·522	Axinite	·552
Nepheline	·524	Augite	·554
Corundum	·525	Dioptase	·554
Quartz	·525	Chrysoberyl	·556
Melinophane	·525	Meionite	·557
Thomsonite	·530	Epistilbite	·561
Harmatome	·532	Clinochlore	·562
Kyanite	·553	Antigorite	·563
Scapolite	·534	Staurotide	·563
Dipyre	·534	Euclase	·567
Peridot	·537	Lime Garnet	·569
Natrolite	·538	Idocrase	·575
Andalusite	·538	Apophyllite	·580
Beryl	·541	Phenacite	·588
Sillimanite	·542	Epidote	·606
Hornblende	·542	Zircon	·645

On a new form of Phosphorite.—By Henry Hamilton Gunn, Associate Royal School of Mines; F.G.S.

IN making an examination of some samples of Phosphorite, recently discovered in Southern Russia, I was much struck by the unusual appearance of the substance, and after a closer examination came to the conclusion that it was a new form of the mineral, and ought to be brought before the notice of this society, in order that its occurrence and physical structure might be recorded and discussed.

The mineral which forms the subject of this paper occurs in rounded masses, varying in size from 5 to 9 inches in diameter. The outer surface is smooth and presents an appearance highly suggestive of the form being due to the action of running water, but upon fracturing several of these balls I found in every instance that they were composed of a number of fibres radiating from the centre, of small size, and of a blueish grey colour, having a hardness of about 4.

These balls are not solid throughout, but near the centre contain fissures similar to those found in Septaria and Clay Ironstone, and these fissures are in every case coated with a thin film of Phosphorite, of a yellowish brown colour, and this I think may possibly be a small quantity of Staffelite.

I have taken the specific gravity of the phosphorite and find it to be about 3·25, and also append an analysis made by Mr Oxton, who found—

Phosphoric Acid	35·18
Carbonic Acid	1·50
Lime	47·88
Oxides of Iron and Alumina	2·65
Silica	8·25
Water in Combination	1·80
Do. at 212°	30
Undetermined	2·97
Equal to Tribasic Phosphate of Lime	76·88
and Carbonate of Lime	3·41

Other analyses have shewn a still greater percentage of phosphoric acid, and some as much as 82 to 84 per cent. of tribasic phosphate, so that in spite of its unpromising appearance it is really rich in the element so valuable for agricultural purposes.

I have carefully examined these specimens to try and discover whether there was any trace of organic origin in them, but without success, and have arrived at the conclusion that they have been formed by slow segregation from the containing rock.

The specimens on which these observations are made were found a few miles to the north east of Kicheneff, upon the flanks of some hills where they had weathered out from the rock, and found thickly strewing the hill sides, large quantities are also found in the valleys, which one may readily credit if it is born in mind that the *form* would facilitate the rapid transportation, and that this harder material, which otherwise would tend by accumulation to protect the rock from denundation, by being rapidly removed, would hasten its destruction, and form considerable accumulations at a lower level where it would find a resting place.

The rocks from which these segregations were derived are according to the excellent survey of the late Sir Roderick Murchison, of lower silurian age, and consist chiefly of limestones and shales. The section which he gives is as follows—

Pentamerus Limestone.
Plata or thin bedded Limestones.
Orthoceratic Limestone.
Bituminous Schist.
Grit and Sandstone.
Shale.

Which of the foregoing beds they have been derived from I have been unable to ascertain, but I feel assured it is from one of the limestones, as a small piece of rock which was attached to one of the specimens was undoubtedly limestone, and I think it possible that further examinations of these rocks might shew that these phosphate deposits occupy the same geological horizon as those recently discovered in Wales.

Strata of this age (at least they are described as such), extend from Kamenetz past Yampol and follow the course of the Dniester for a distance of about 45 miles, both banks of which are formed of these rocks, which extend for a distance of about 5 or 6 miles on each side of the river.

DISCUSSION.

Mr. Sorby thought the nodules had the appearance of masses of organic origin.

Mr. Collins pointed out that they contained iron pyrites, although the analyses made no mention of sulphur. He thought they might be pseudomorphous after ordinary pyritous nodules.

Remarks on the distribution of Minerals in North Devon.—By Townshend M. Hall, F.G.S., &c.

THE district to which the following notes refer is contained in sheets 26 and 27 of the one inch Ordnance Survey Maps, and embraces an area of about 985 square miles, the northern boundary being formed by the Bristol channel, and that on the south by a line drawn through the town of Okehampton. The rocks composing this district belong to the Devonian and Carboniferous systems, with the exception of a small portion of new red sandstone and a patch of Greensand, occupying a few acres. The two older systems present a regular sequence of beds from north to south, which, interrupted by the granite of Dartmoor, are represented to a greater or less extent by a similar series in the southern portion of the county.

In the Greensand at Orleigh Court, near Bideford, manganese and iron oxides are found together with flint and chert. In the carboniferous series a line of intermittent beds of Anthracite runs from Barnstaple Bay to Umberleigh Station, a distance of 13 miles. These beds vary in thickness from 6 inches to 14 feet. Small strings of iron ore, occasionally mixed with oxide of manganese, are also rarely met with. The quarries of Venn and Swimbridge, in the Mountain Limestone, afford minute crystals of calcite; whilst, in a band of indurated shale near South Molton, Wavellite was first discovered, about the year 1785.

The upper Devonian, in North Devon, admits of the three following subdivisions:—

1. Pilton Slates.
2. *Cucullæa* Sandstone.
3. Pickwell Down Sandstone.

The Pilton Slates, which are very fossiliferous, contain copper ores in several localities, with galena and blende; but in the cucullæa sandstone, which is also fossiliferous, none of these ores have been found. The Pickwell Down sandstones are a series of red rocks, entirely destitute of organic remains; veins of hematite with oxides

of manganese are abundant, and have been worked in several localites. The northern boundary of this metalliferous deposit is formed by a narrow band of porphyritic felstone, which runs along the division between the upper and middle Devonian groups.

The middle Devonian, like the upper, consists of three subdivisions.

1. Morthoe Slates.
2. Ilfracombe slates and limestones.
3. Martinhoe or Hangman beds.

The Morthoe slates are unfossiliferous ; they are characterized by the abundance of quartz veins, which intersect the slates in every possible direction ; but I know of no instance of the occurrence of metallic veins. In the Ilfracombe beds argentiferous galena has been worked at Combmartin since the year 1294, and is associated with the ores of copper, small quantities of blende, and antimony. In the limestone bands Aragonite is not uncommon. The Martinhoe or Hangman grits contain beds of iron ore, in a line parallel to the strike of the rock.

The Lower Devonian is divided into (1) the Lynton bed, and (2) the Foreland Sandstones and grits. The first of these is fossiliferous, with a general absence of minerals ; in the Foreland beds, which are the lowest known members of the series, iron again appears.

Conclusions.

From the carboniferous district no general deductions can be drawn, since it is so deficient in mineral wealth ; but the Devonian beds ranging between Lynton and Barnstaple present several points of interest, which may thus be summed up.

Each of the eight beds, which have already been specified, have a distinct mineral character.

The greatest amount of resemblance is to be found in the Foreland, Martinhoe, and Pickwell Down series, as they are all characterized by the presence of iron, and the absence of organic remains.

The Ilfracombe and Pilton groups resemble each other in being fossiliferous, and in yielding lead, copper, and zinc. They each also contain calcareous bands.

From the Lynton, Morthoe, and *Cucullæa* beds no conclusions can be drawn, as they have no analogy either with each other, or with any of the other groups.

DISCUSSION.

Mr. J. H. Collins remarked that it was interesting to find the productiveness of the mineral lodes confined to certain beds in North Devon, as in Cornwall. In the neighbourhood of Truro, Mr. T. Clark had shewn that the productive portions of the lead lodes of West Chiverton and other mines were confined to certain beds of moderately hard killas.

Prof. Harkness said that he regarded the Pilton beds as the base of the carboniferous series and not Devonian at all. He thought they were the equivalents of the carboniferous slates of Ireland, in which the Irish wavellite occurred.

M. Moissenet thought the productive deposits occurred in certain beds rather than others, simply because those beds were more favourable for the production of open fissures, owing to peculiarities of mineral character.

Query.—Can any member give information respecting the minerals and ores, and their mode of occurrence in the Lötchenthal, which runs N from the Valais, Switzerland?

M. H.

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ORIGINALLY PRINTED IN GREAT BRITAIN BY MESSRS. LAKE AND LAKE, TRURO. REPRINTED OFFSET LITHO BY BIDDLES LTD., THE CITY PRESS, GUILDFORD, SURREY